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(54) Locating optical radiation

(57) Optical radiation source locating apparatus such as a static-split infra-red tracker where a focussed or defocussed source image is formed on a sensor array, may suffer from atmospheric shimmer producing uneven illumination of the receiving aperture of the apparatus and hence uneven image brightness. In the apparatus disclosed herein, a matrix of lenses 4 or, alternatively, "flats" on a lens surface or areas of intersection between crossed prisms or cylindrical lenses, define an array aperture portions, radiation received through which is directed to form respective source images superimposed upon one another on the sensor array 5.

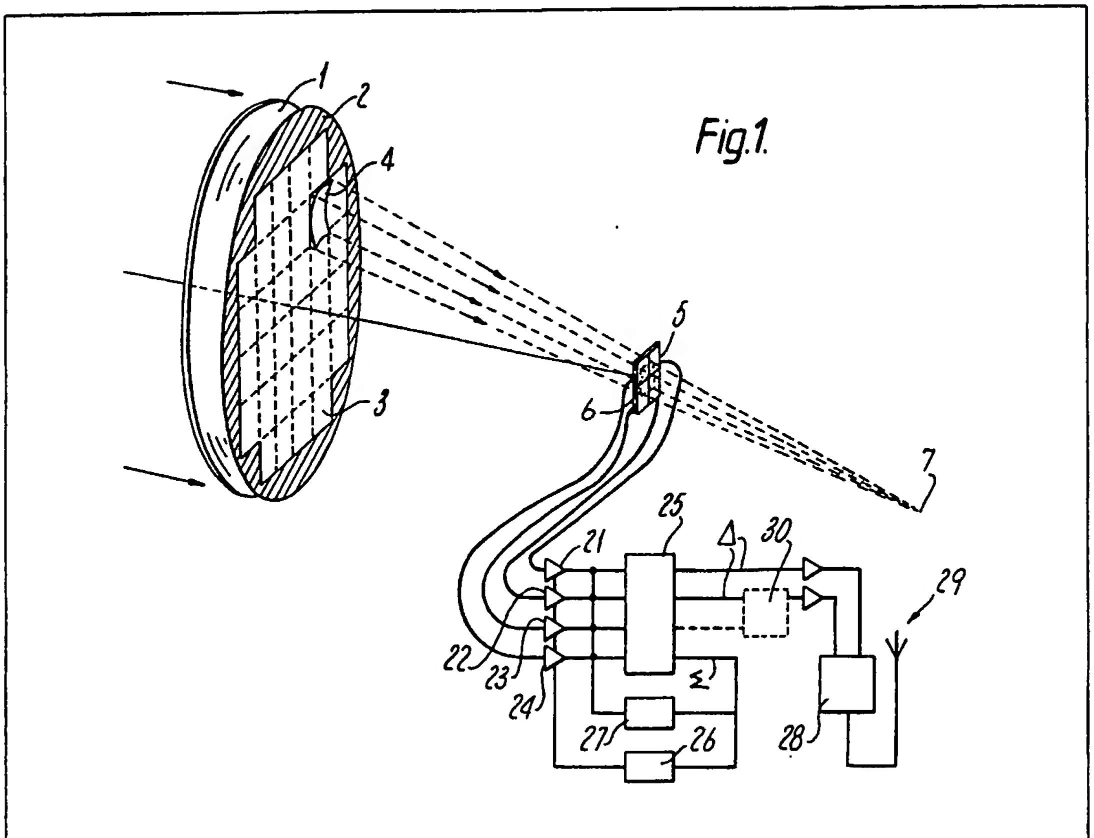

Fig.1.

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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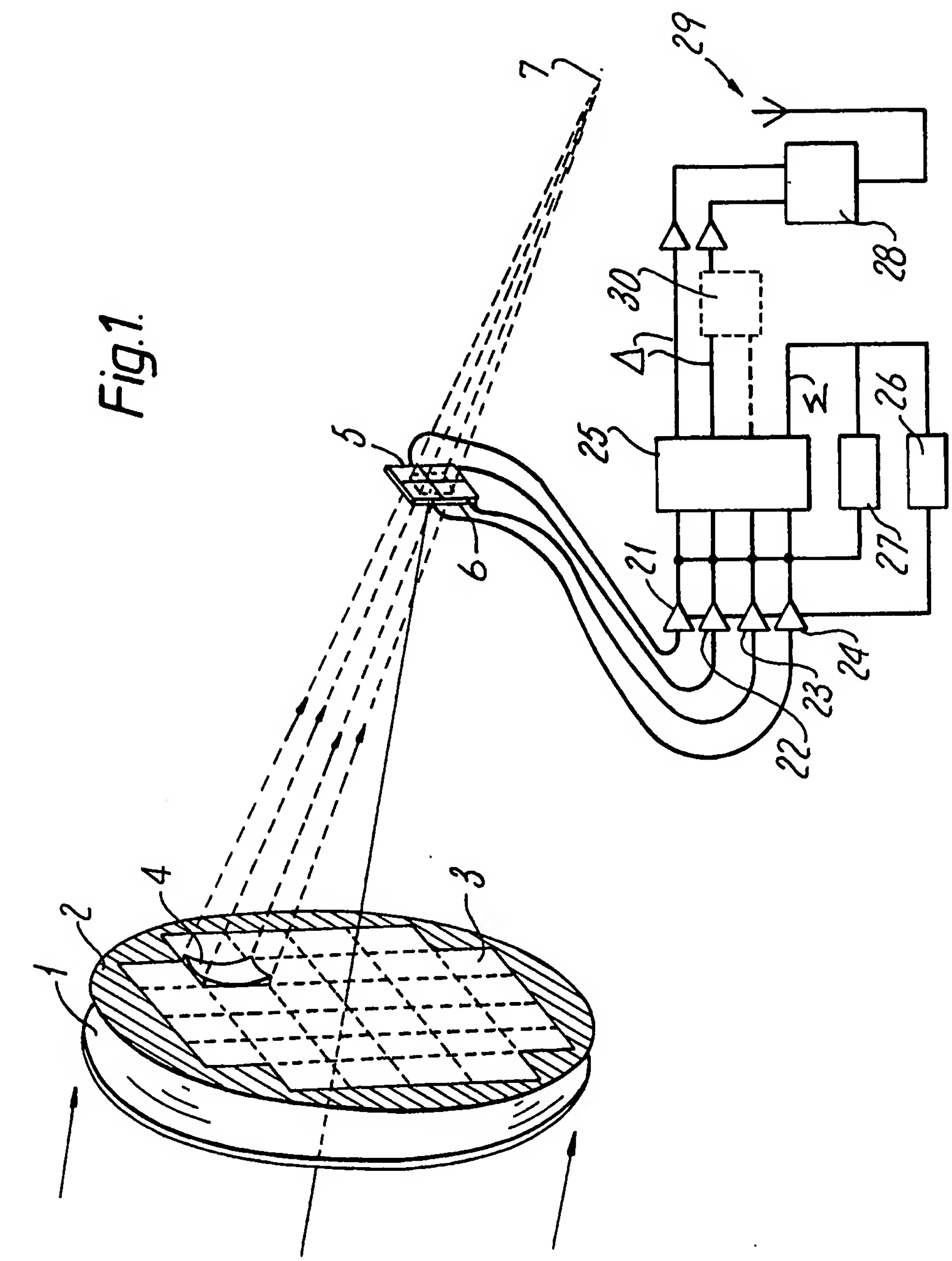


Fig.1.

Fig. 2.

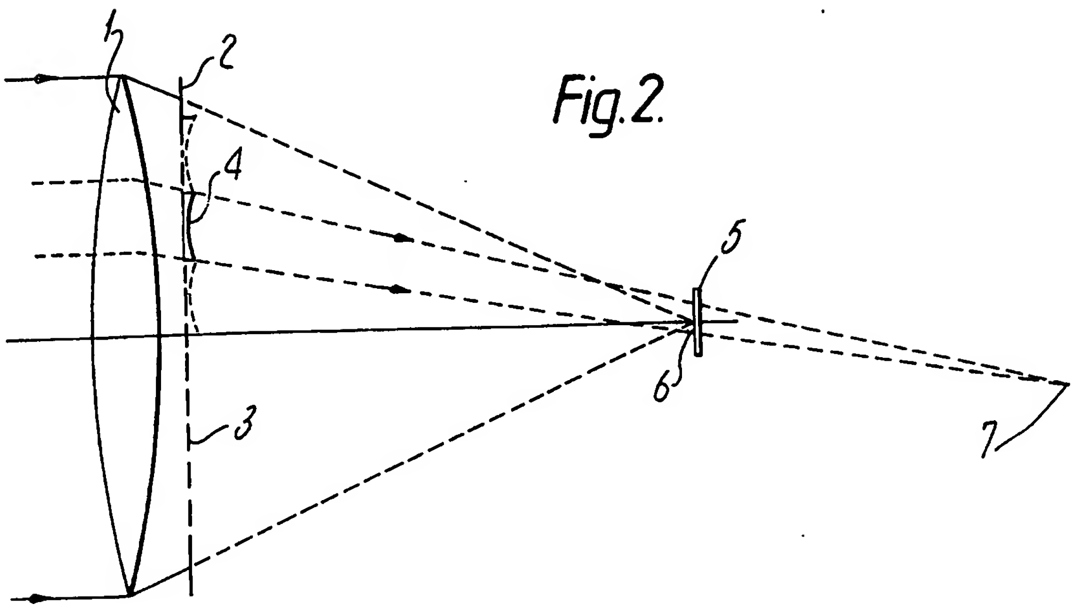
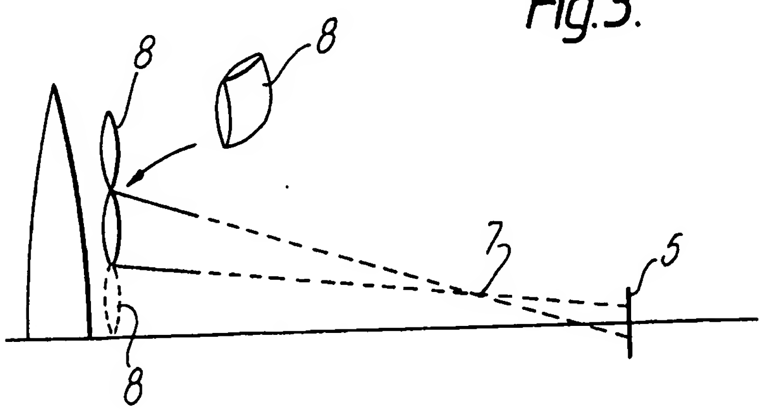


Fig. 3.



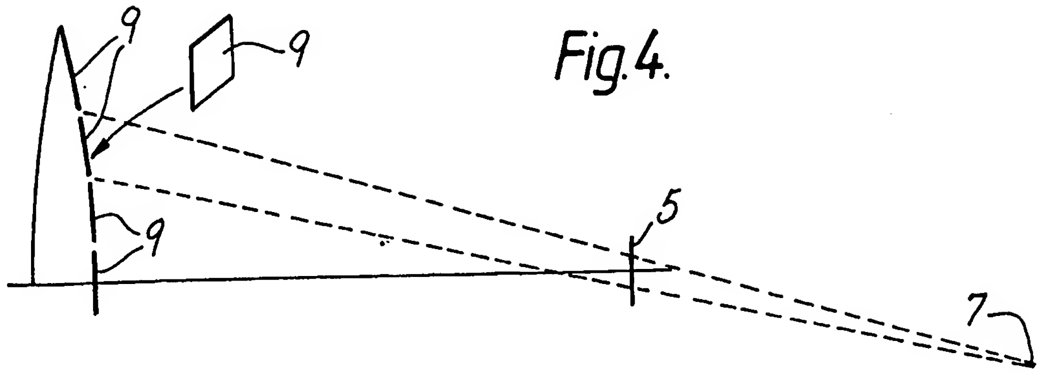


Fig.4.

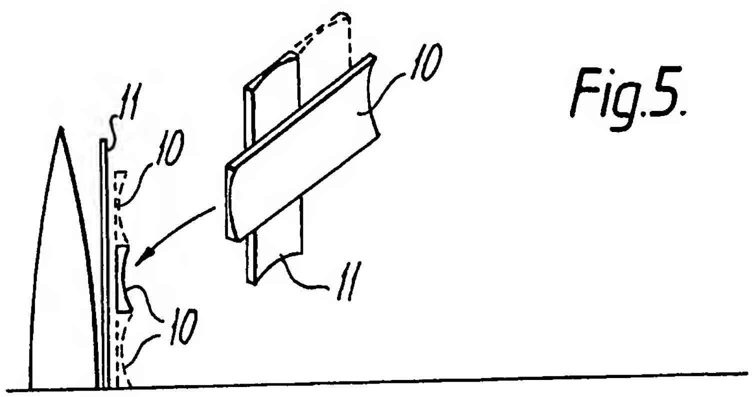


Fig.5.

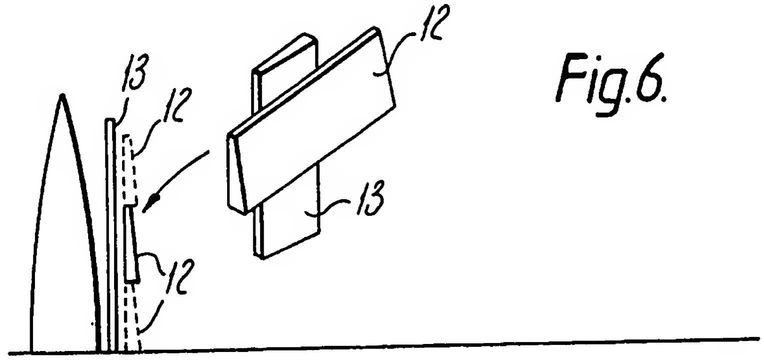


Fig.6.

Fig. 7a.

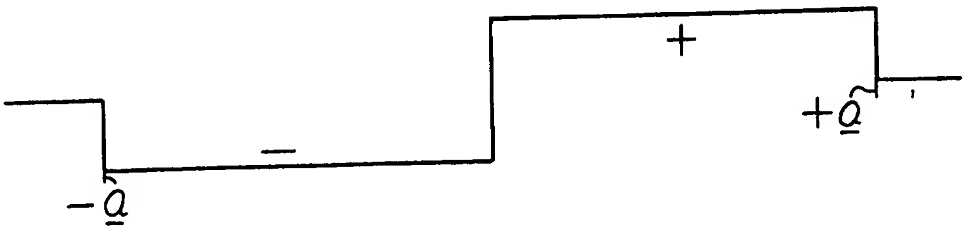


Fig. 7b.

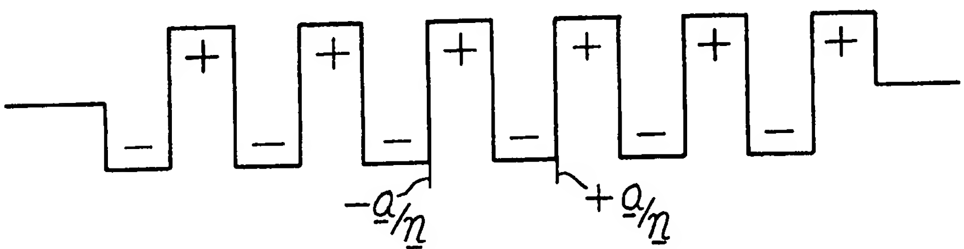


Fig. 7c.

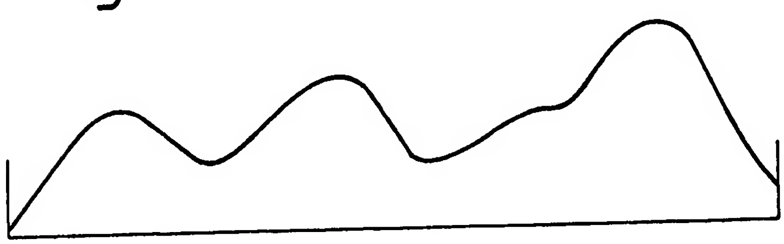


Fig.8a.

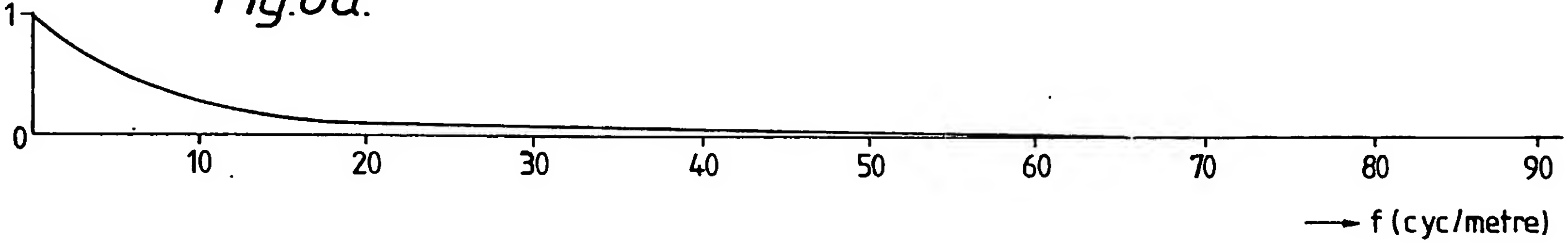
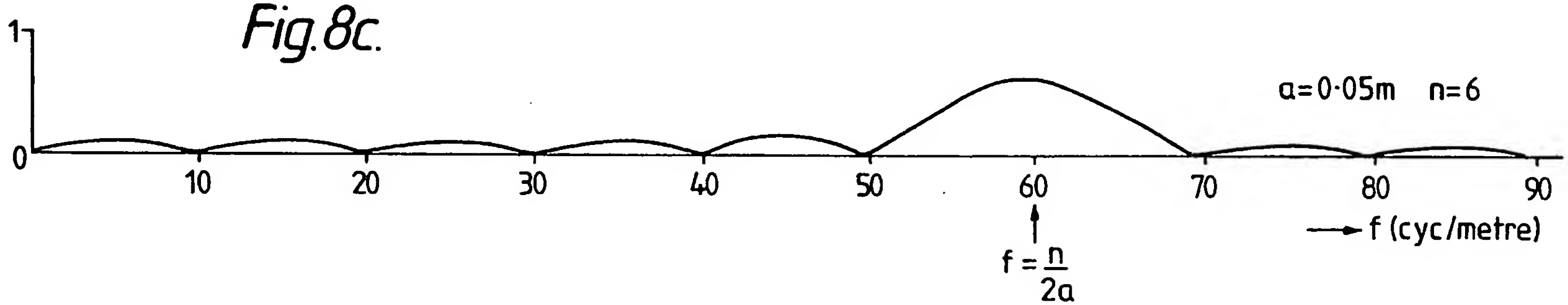


Fig.8b.

Fig.8c.



SPECIFICATION

Locating optical radiation

This invention relates to optical radiation source locating apparatus for example to optical trackers of the kind in which an image of a distant radiation source to be tracked, such as an I.R. beacon carried by a missile, is optically projected, sometimes partially defocussed, on to a photo electric detector having two or more distinct light-sensitive areas each of which produces a separate electrical output and voltages proportional to the sum and difference of the detector outputs are derived and used as error signals representing the displacement of the image with respect to one or more orthogonal axes of the detector.

The conventional static split optical tracker of this kind has to compromise between good linearity and good performance with regard to optical shimmer due to atmospheric turbulence. Such an optical tracker may comprise four radiation sensitive elements arranged to form quadrants of a square array onto which is projected the defocussed image of the radiation source being tracked, and which produces error signals with respect to two orthogonal axes. For good linearity a square lens aperture is used, and a sharp edged, uniformly illuminated square radiation patch is projected on to the detector as a defocussed image of the distant point source of radiation. This gives a linear error-voltage characteristic for angular misalignment of the square patch with respect to the array, since such misalignment is equivalent to convoluting the functions of a pair of rectangular apertures.

Unfortunately atmospheric shimmer causes the radiation distribution on the detector to be non-uniform and fluctuating, with consequent apparent errors. It also produces an apparent angular deviation of the line of sight. The usual solution to the problem of non-uniform illumination is to focus the radiation to a point onto a diffusing screen and project the diffuse patch onto the detector array. In this arrangement all spatial variations of intensity in the direction which would cause errors are completely cancelled. However, since the projected radiation patch now has a non-uniform profile, the error characteristic of the tracker is non-linear. This may be adequate in systems in which a good nulling process takes place, although there is usually considerable attenuation, but it is unsatisfactory where off axis use is envisaged. This is particularly so when multiple array quadrant detectors are used to cover a wider field of view and the transfer from one set of quadrants to an adjoining set must be made with minimal transient error. In addition. suitable diffusing screens for use in the focal plane of systems working in the far IR waveband are not easy to produce.

According to one aspect of the invention, there is provided optical radiation source locating apparatus comprising detector means defining an array of radiation sensitive portions and image forming means which is operable for defining a plurality of aperture portions for receiving radiation from said source and for ensuring that the radiation received *via* the respective aperture portions is superimposed onto a common area of said array.

According to another aspect of the invention, there is provided a device, for use in optical radiation source locating apparatus which comprises detector means defining an array of radiation sensitive portions, the device comprising radiation direction changing means through which radiation can pass from one side to the other, deviating as it does so, and which is operable to define a plurality of substantially regularly orientated radiation passing apertures, the apertures preferably being substantially square or rectangular, and being further operable during use of the device for directing radiation received through the respective apertures into superimposition onto a common area of said array.

By way of example, the device may comprise a matrix of positive or negative lens elements or two orthogonal arrays of plane prisms or of elongated positive or negative cylindrical lenses, or it may comprise a lens on which there has been formed a regular array of square flattened surface portions. The aperture portions defined by the matrix need not be identical in size provided the element focal lengths are chosen to form identically sized images at the detector.

It will be appreciated that, although the invention is primarily concerned with infra-red radiation, it is also of use by suitable choice of optical materials for the full optical wavelength range including the ultra-violet and visual bands.

In one embodiment of the present invention an optical tracker has an objective comprising a conventional lens arranged to form a square uniform image (neglecting diffraction) of a distal radiation source onto a set of four photo-electric detectors in quadrant configuration and a multi-apertured matrix of optical elements arranged near the lens, *i.e.* not in the focal plane of the lens as in the case where the known diffusing screen is used. The square image is arranged to be of the same size as one of the detector elements, by suitable choice of detector position, and is formed by the superimposition of the multiplicity of images formed by the individual apertures which are square. The four detector elements are connected in a sum and difference arrangement such that the respective electrical outputs vary continuously and differentially in response to the relative amounts of the projected radiation pattern falling on the detectors. Such an arrangement may be de-

signed to have a relatively linear characteristic relating angular position of the source to the output voltage comprising the difference signal normalised to the sum signal and at the same time to have a degree of atmospheric shimmer rejection by ensuring that each square image is formed by an aperture which is small compared with the "scale of turbulence", resulting in only a small spatial variation in intensity across its area and therefore across the image on the detector and that the multiplicity of such images, being generally uncorrelated, will produce a smoothing effect on the image intensity spatial distribution when superimposed at the detector.

For a better understanding of the invention, reference will now be made, by way of example, to the accompanying drawings, in which:—

Figure 1 is a diagrammatic view of part of an optical tracker comprising a multiple aperture defining matrix and a four element detector array,

Figure 2 is a diagram showing the principle of operation of the matrix of Fig. 1,

Figures 3 to 6 are diagrams illustrating the construction and operation of respective embodiments of a multiple aperture defining usable in the Fig. 1 tracker,

Figures 7(a), 7(b) and 7(c) are diagrams for explaining the effect on shimmer response of the use in an optical tracker of a multiple aperture defining matrix, and

Figures 8a to 8c are three curves illustrating the spatial frequency distribution of typical shimmer effects and the shimmer response of an optical tracker with and without a multiple aperture defining matrix.

The tracker of Fig. 1 comprises an objective lens 1, with a four element static split or quadrant detector 5, at its focal plane and on the optical axis of lens 1. Thus, were it not for the presence of a multiple aperture defining matrix device 3, a distant point source of radiation on the optical axis would be imaged to a point image on the detector as shown in Fig. 2.

The output signals from the four detector elements are fed *via* respective amplifier elements 21 to 24 to a sum and difference signal forming circuit 25 which forms a signal Σ representing the sum of the detector signals and difference signals Δ representing the differences between the radiation received by the right and left-hand columns of detectors and between the radiation received by the upper and lower rows of detectors and thus representing also the position of the radiation source in relation to the tracker axis along the two corresponding axes. The sum signal Σ is used to normalise the detector signals by way of automatic gain control circuit 26 and a phase locking circuit 27 while the difference signals Δ are amplified and fed to a suitable data processing apparatus 28 from which data may be fed by way of example to a command link 29 for transmission to guide the missile.

It will be appreciated that the detector array 5 could be extended by the addition of more detector elements, for example there could be six such elements. These can be regarded as two groups of four elements (two of them being common to each group) and then, as shown by the dashed lines in Fig. 1, a further difference signal may be formed representing the difference between the radiation received by the additional row or column of elements and the adjacent row or column and a changeover switch 30 is provided to select the appropriate difference signal for transmission to the apparatus 28.

The matrix 3 is introduced in the optical path near to and either in front of, or behind, the objective lens 1 (in which position it is shown in Figs. 1 and 2). It comprises a regular matrix of contiguous identical lens elements of which one (4) is shown in detail. The lens elements are negative in the example shown but they could be positive.

The action of each element 4 is to defocus locally the image of the distant point source of radiation to produce a sharp square image 6 in the plane of the detector and of size equal to that of one of the detector elements. Alternative angular error characteristics may be achieved by making the image smaller than this. The focal point of the combination of objective lens 1 and the element 4 is shown at point 7. Because the detector 5 is situated at the focal plane of objective lens 1, all of the square images of the other elements of the matrix 3 coincide at the detector 5. As the distant radiation source moves away from the optical axis, the square image will traverse the detector array so illuminating the detector elements differentially giving rise to error voltages linearly proportional to the angular displacement. In order to avoid non-square images, those remaining areas 2 of the objective lens not large enough to include one complete matrix element are masked. Staggered columns of lens elements may be used to minimise the masked area.

For manufacturing purposes it may be advantageous to use alternative forms of construction. Fig. 3 shows an arrangement with positive lenses 8, whose focal points are now between the objective and detector but which produce the same sized image on the detector 5. It may for some purposes be advantageous to use alternate positive and negative lenses across the matrix.

Fig. 4 shows an arrangement whereby the effect of negative lenses has been produced by forming flats 9, on the surface of the objective lens.

Fig. 5 shows an arrangement of orthogonally mounted cylindrical lenses 10, 11, which may be easier to fabricate and assemble than individual elements.

Fig. 6 shows a similar arrangement of orthogonally mounted prisms 12, 13. The prism angles are progressively increased as a function of the distance of the element from the optical axis.

The matrix of Fig. 1 has thirty-two lens elements such as the element 4 but there could be more or less than this. Up to a limit of around a hundred the more there are the better. In a preferred case, the matrix defines an eight by eight array of apertures, *i.e.* there are sixty-four lens elements or flats on a lens as in Fig. 4 or aligned portions of the orthogonal arrays of lenses or prisms of Figs. 5 and 6.

As discussed above, the effect of atmospheric shimmer which particularly applies to static split trackers is the non-uniform illumination of the entrance pupil. For a distant point source of radiation this intensity distribution is sharply imaged at the detector plane for the so called defocussed system. The non-uniform distribution of intensity differentially illuminates the detector giving rise to an apparent angular displacement even for an on-axis source of radiation.

Fig. 7(*a*) shows, for a static-split tracker which has a square aperture or entrance pupil of side length 2(*a*) and in which a single defocussed image of a distant on-axis source is being formed on a pair of side-by-side radiation sensor elements, the single-stepped waveform of the function relating the difference Δ between the sensor element signals, to variation in illumination across the aperture and hence also across the sensor element pair. The waveform of the same function when a plurality of superimposed images each comprising radiation received *via* a respective one of *n* side-by-side portions of the same aperture is shown in Fig. 7(*b*). Meanwhile, the actual pattern of illumination intensity variation across the aperture, measured as vertical line integrals, can be represented by a waveform such as that shown in Fig. 7(*c*). Because of this variation of intensity across the aperture, the difference signal Δ will vary in amplitude in dependence upon the relative positions of the pattern and the aperture—if the aperture is moved linearly relative to the pattern, the signal Δ will vary in a manner determined by the shape of the pattern waveform. Now, the waveform of Fig. 7(*c*) can be resolved into a series of sinusoidal components of different spatial frequencies, each associated with a corresponding sinusoidal component of the variation of signal Δ. For the single image case, Fig. 7(*a*), the peak amplitude of each sinusoidal component of the variation of signal Δ is given by the expression $(1 - \text{Cos } a\omega)/a\omega$, where $\omega = 2\pi f$ and f is the spatial frequency of the component. For the multiple image case of Fig. 7(b), the corresponding expression is:

$$\frac{1 - \text{Cos } a\omega/n}{a\omega/n} \cdot \frac{\text{Sin } a\omega}{n.\text{Sin } a\omega/n}$$

The variation of these two expressions for a range of spatial frequency and for an aperture $2a$ of 0.1 metres, are plotted in Figs. 8*b* and 8*c* respectively while Fig. 8(a) shows a typical amplitude *versus* spatial frequenc waveform for atmospheric shimmer. By comparing Figs. 8(*a*) to (*c*), it will be appreciated that the shimmer response for the multiple-image case is much lower than that of the single-image case in the frequency region where the shimmer effect is large and that the multiple image shimmer response has a maximum only in a region where the shimmer effects are very small.

It will be appreciated that the term "optical radiation" as used herein means not only visible radiation but also radiation in the invisible ranges such as infra-red radiation. Also, the term "source" is not limited to an element which actually generates radiation—instead it could mean an element which is reflecting received radiation for example.

CLAIMS

1. Optical radiation source locating apparatus, for example infra-red sensitive missile tracking apparatus, having an array of radiation sensitive elements and image forming means for forming on said array an image of a radiation source to be located, characterised in that the image forming means is operable for defining an array of radiation-receiving aperture portions and for directing the radiation received *via* said aperture portions to form respective source images superimposed upon one another on said array of radiation sensitive elements.

2. Apparatus according to claim 1, wherein the image forming means comprises a matrix of positive and/or negative lens elements (4, 8) defining respective ones of the aperture portions.

3. Apparatus according to claim 1, wherein the image forming means comprises crossed arrays of side-by-side elongate lenses or prisms (10, 11 or 12, 13).

4. Apparatus according to claim 1, wherein the image forming means comprises a lens with a matrix of deformed surface portions (9) thereon.

5. Optical radiation source locating apparatus substantially as hereinbefore described with reference to any figure of the accompanying drawings.

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